

Fifth International Information Exchange Forum on

**"Safety Analysis for Nuclear Power Plants of
WWER and RBMK types"**

15 - 20 October 2000, Obninsk, Russia

**Specific Thermal-Hydraulics Analyses for
Integrity Evaluation of
WWER-440/213 Type Reactor**

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The integrity assessment of RPV are carried out in two phases.

Phase 1: ⇒ Thermal-hydraulic system calculation
 ⇒ Mixing calculation

Phase 2: ⇒ Structure temperature/stress analysis
 ⇒ Fracture mechanics analysis

Thermal-hydraulic analysis gives following parameters for the wall temperature and stress calculation:

- downcomer temperature field**
- coolant-to-wall heat transfer coefficient downcomer**
- primary circuit pressure**

Thermal-hydraulic system calculation

Thermal-Hydraulic code

⇒ RELAP5/Mod3.2.2β

Thermal-Hydraulic model

⇒ 6-loops model for WWER-440/213 Type Reactor Bohunice V-2 NPP

⇒ primary circuit

⇒ secondary circuit

⇒ safety-important systems

⇒ controls

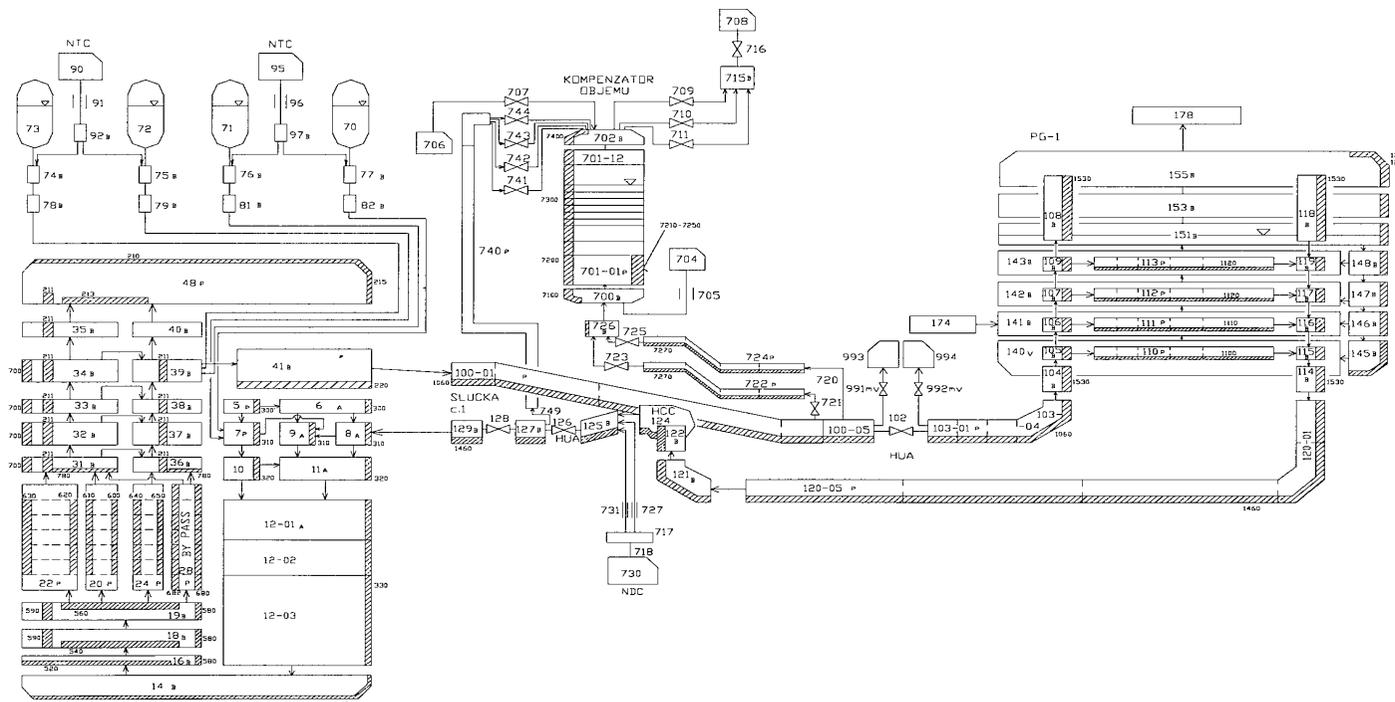
ECCS injection

⇒ 3 HPI pumps

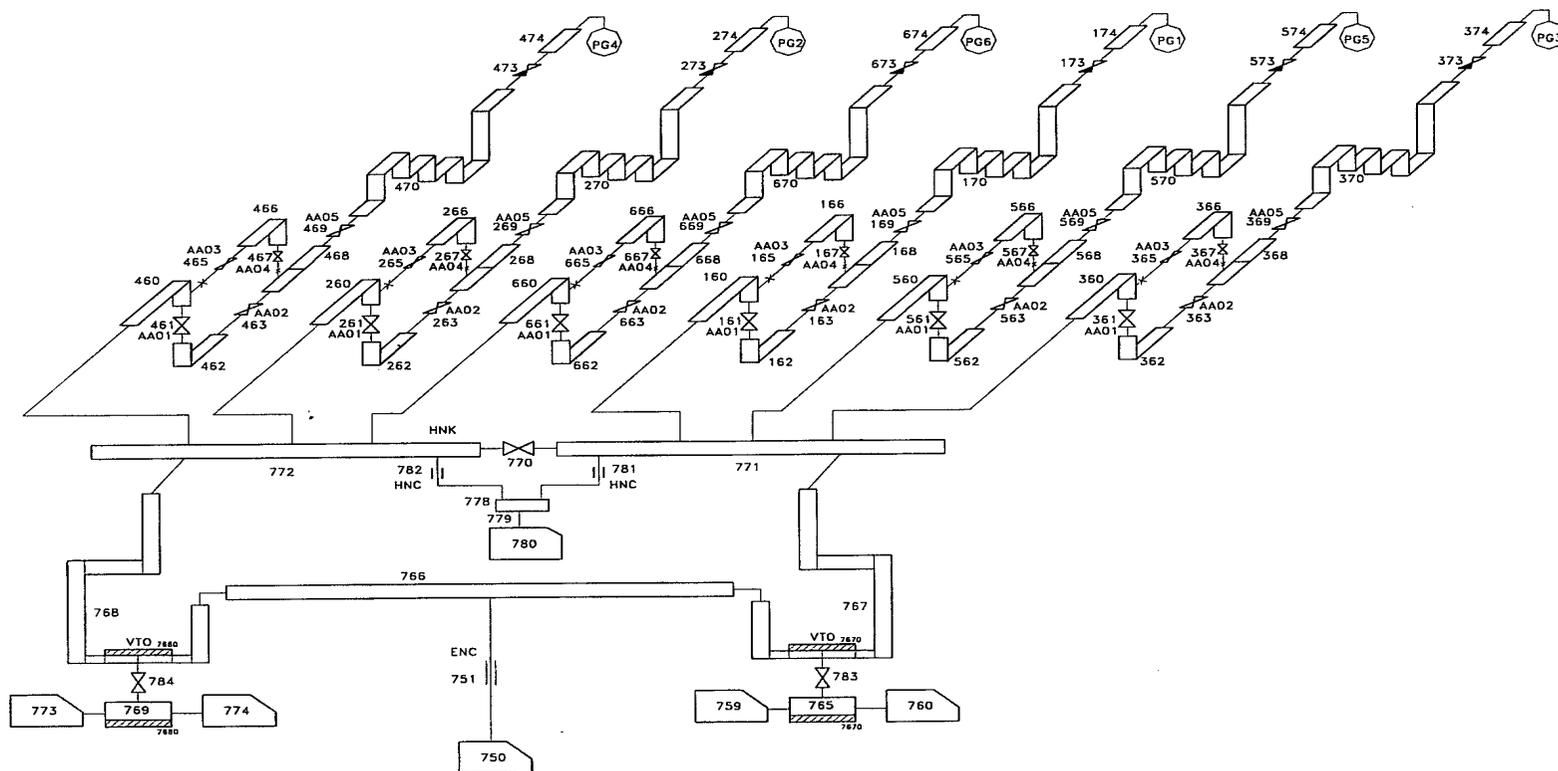
⇒ 3 LPI pumps

⇒ 4 accumulators

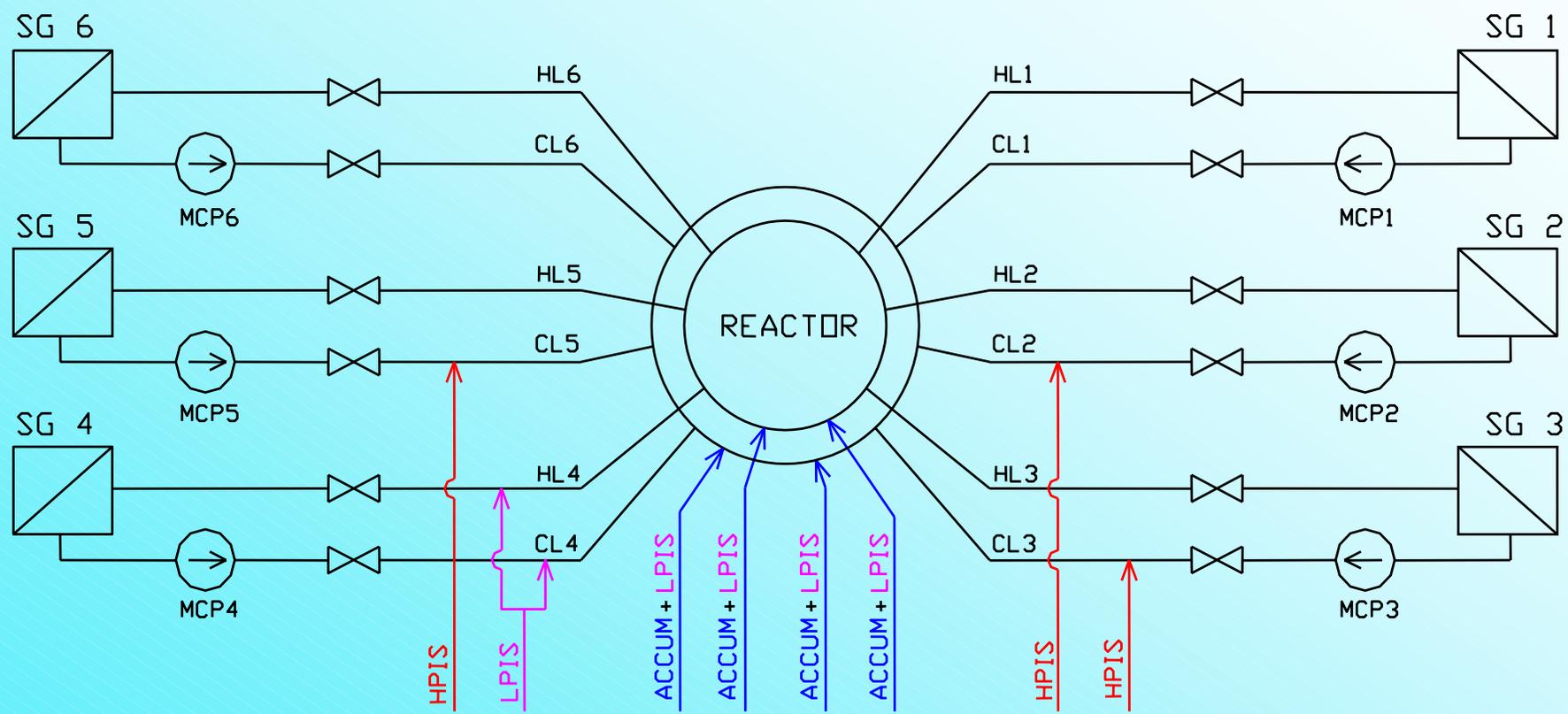
Primary Circuit Nodding Scheme



Secondary Circuit Nodding Scheme



Safety injection system



Mixing calculation

Mixing calculation code

⇒ MIXEBO

⇒ based on the REMIX/NEWMIX code

Thermal-hydraulic analysis transient selection

-based on IAEA guidelines

➤ IAEA-EBP-WWER-01

Guidelines For Accident Analysis of WWER NPP

➤ IAEA-EBP-WWER-08

Guidelines On Pressurized thermal shock analysis for WWER NPP

Review of analysed **Non-LOCA** calculations

- Increase in heat removal by secondary side
 - main stem line break

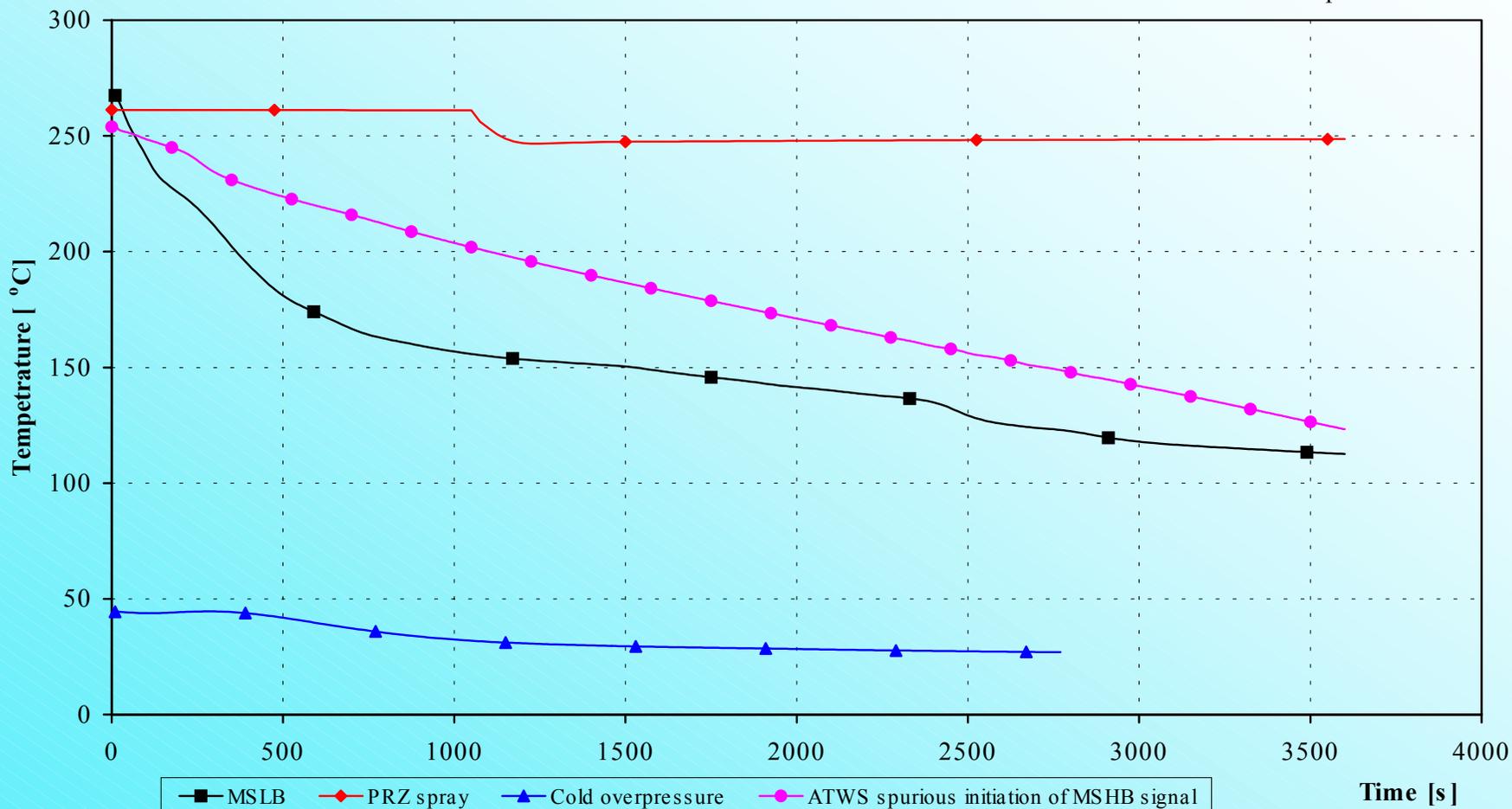
- Decrease in heat removal by secondary side
 - Feed & Bleed procedure

- Increase in reactor coolant inventory
 - cold overpressure (ECCS start)
 - inadvertent start of PRZ sprays

- ATWS
 - reactor coolant pumps stop
 - loss of off site power
 - loss of main feedwater flow
 - spurious initiation of main steam header break signal
 - inadvertent opening of one steam generator safety valve
 - uncontrolled withdrawal of a control rod group during power operation

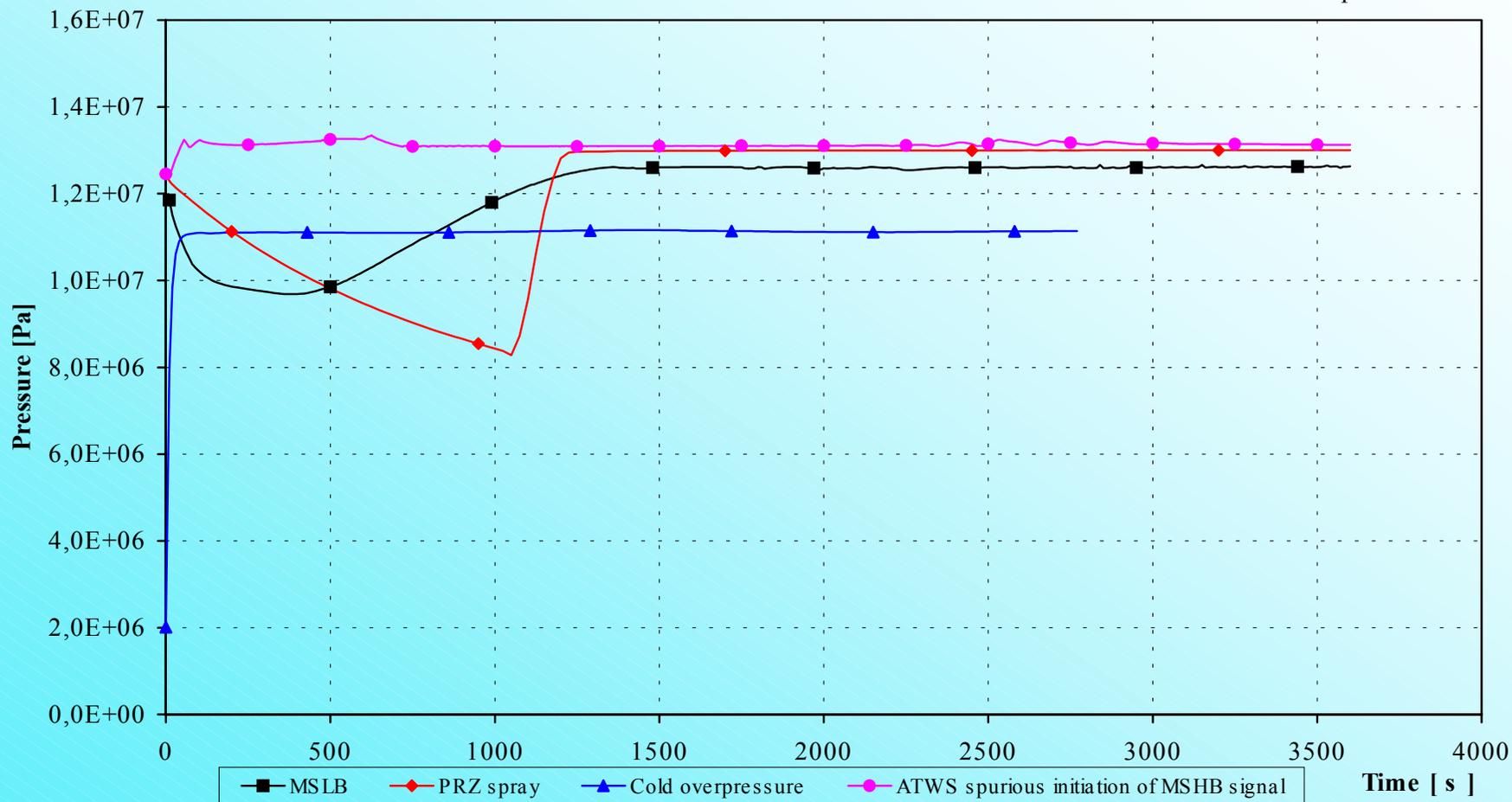
Non-LOCA - CORE INLET COOLANT TEMPERATURE

VÚJE Trnava a.s.
Relap5/Mod3.2.2.



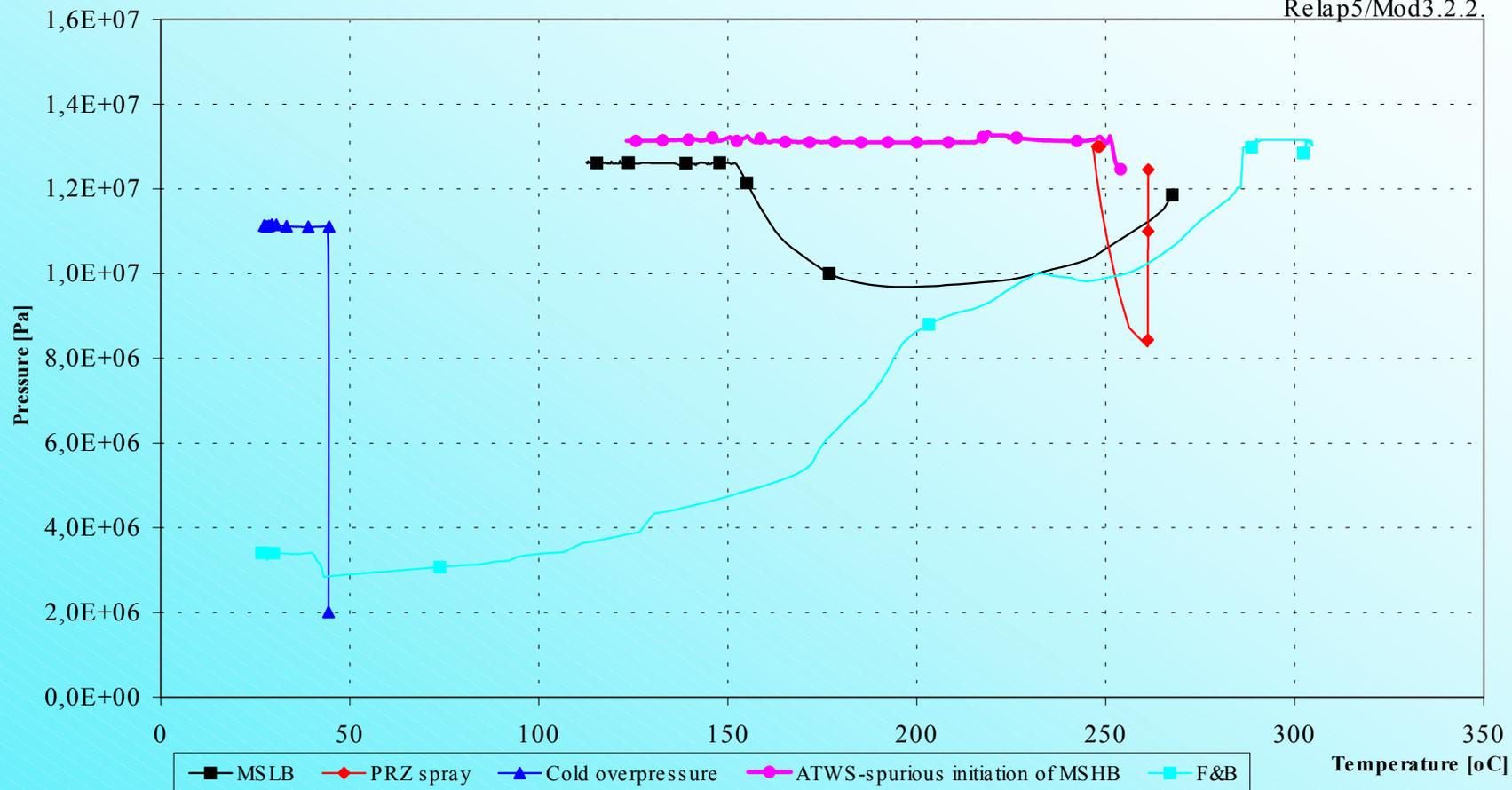
Non-LOCA - CORE OUTLET PRESSURE

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Relap5/Mod3.2.2.



Non-LOCA Analysis

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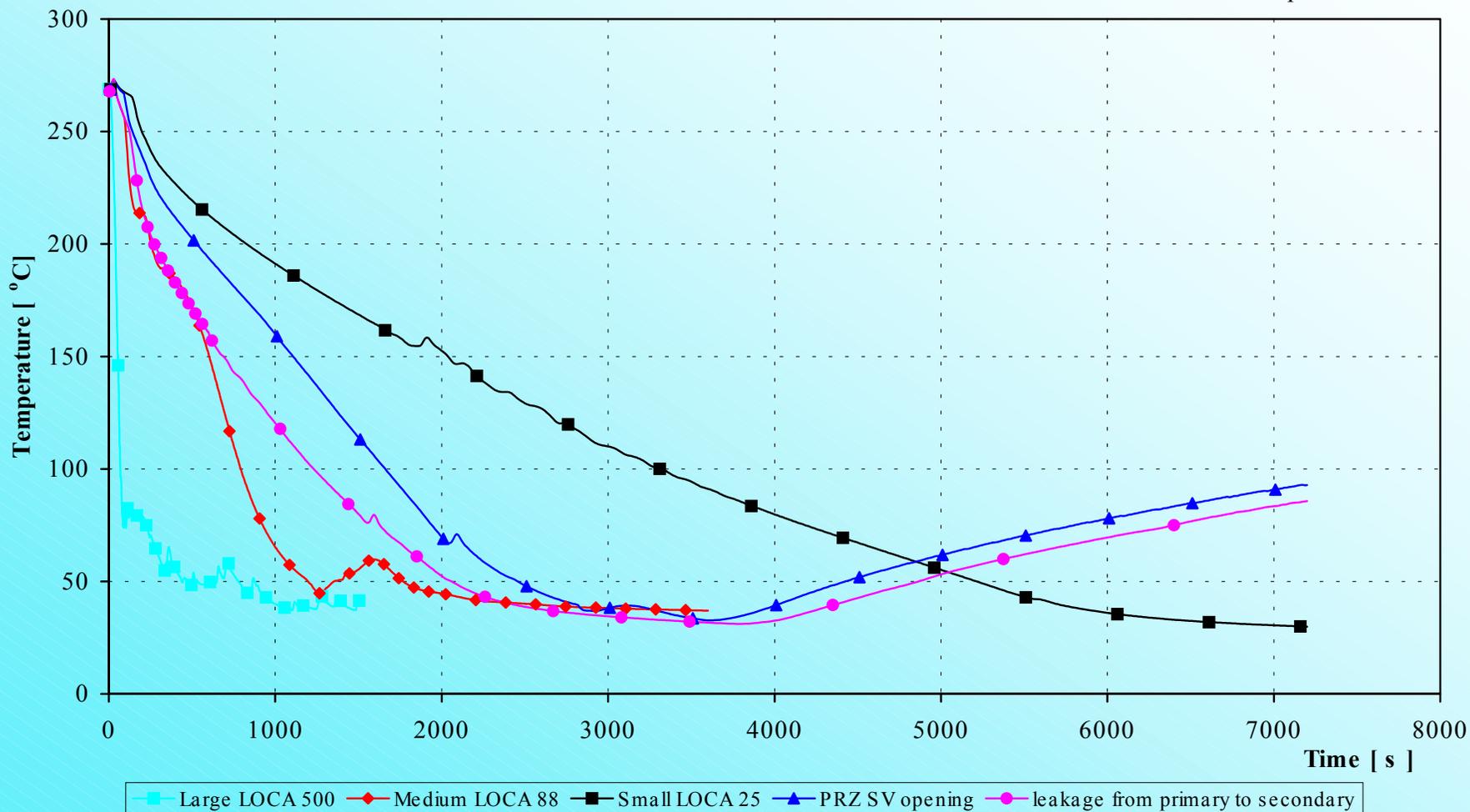


Review of analysed **LOCA** calculations

- Large LOCA \varnothing 500
- Medium LOCA \varnothing 150, \varnothing 135, \varnothing 100, \varnothing 88, \varnothing 65
- Small LOCA \varnothing 50, \varnothing 25, \varnothing 13
- Stuck open PRZ SV
- primary to secondary leakage accidents
 - SG tube rupture
 - SG collector cover opening

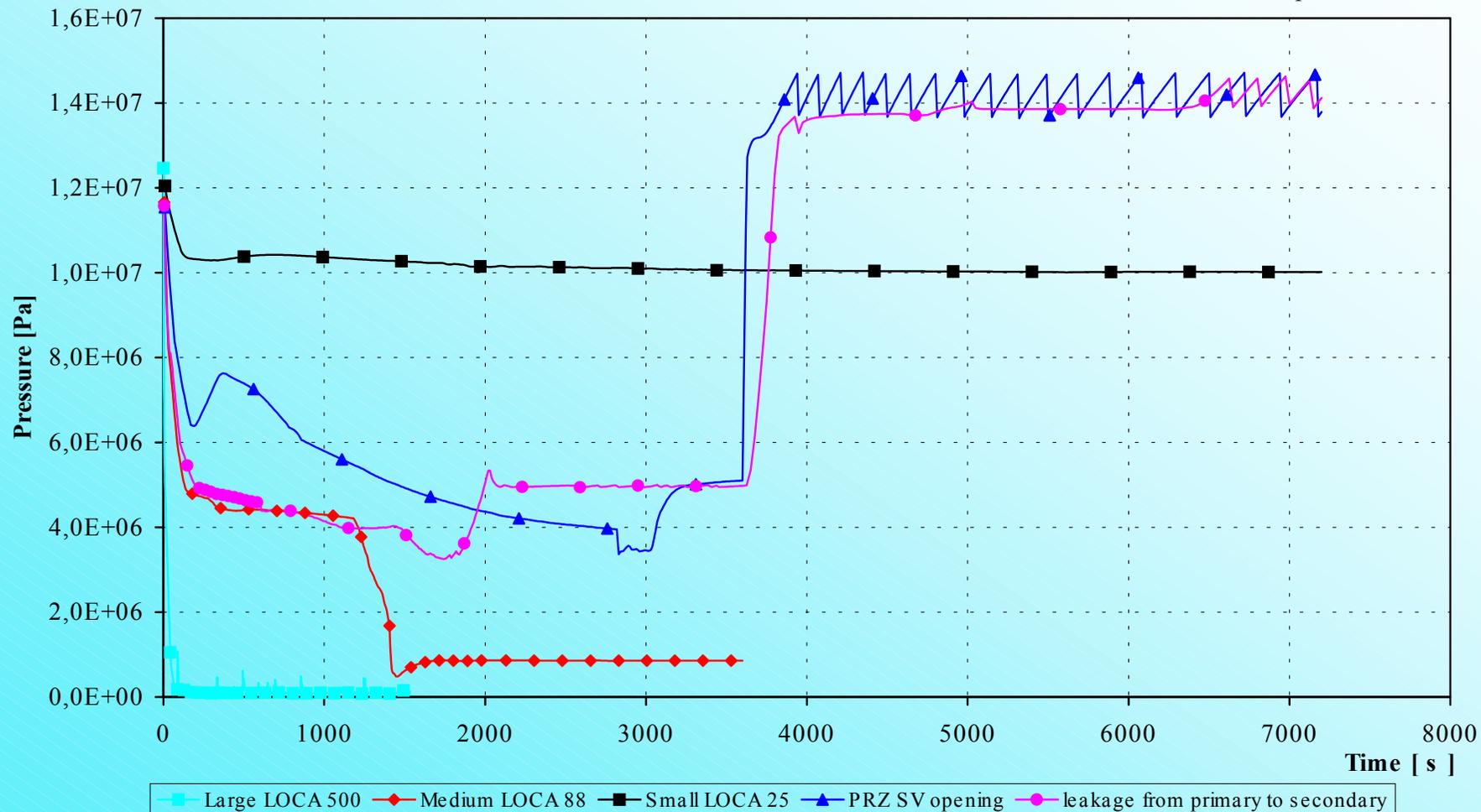
LOCA - CORE INLET COOLANT TEMPERATURE

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Relap5/Mod3.2.2.



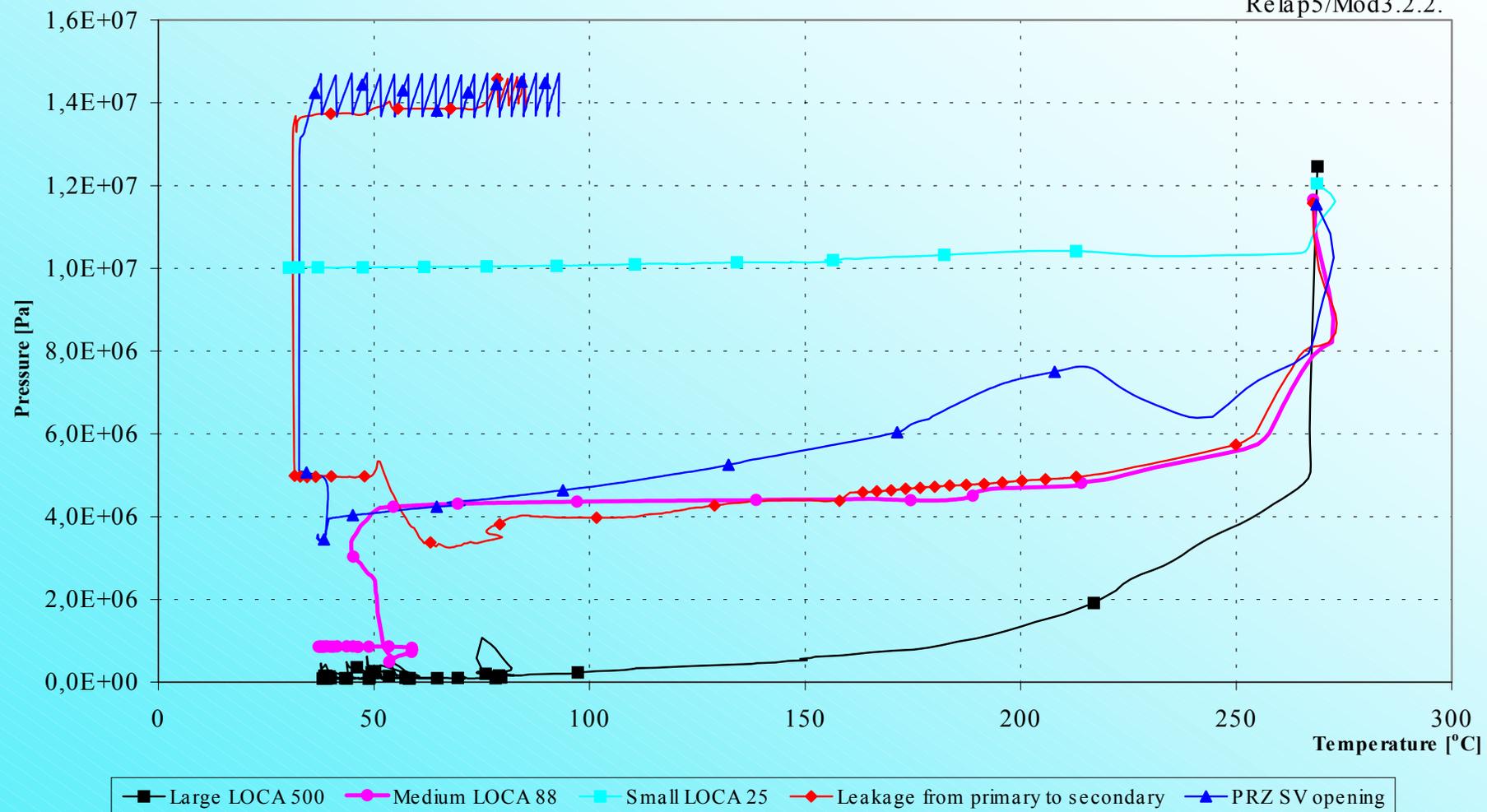
LOCA - CORE OUTLET PRESSURE

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Relap5/Mod3.2.2.

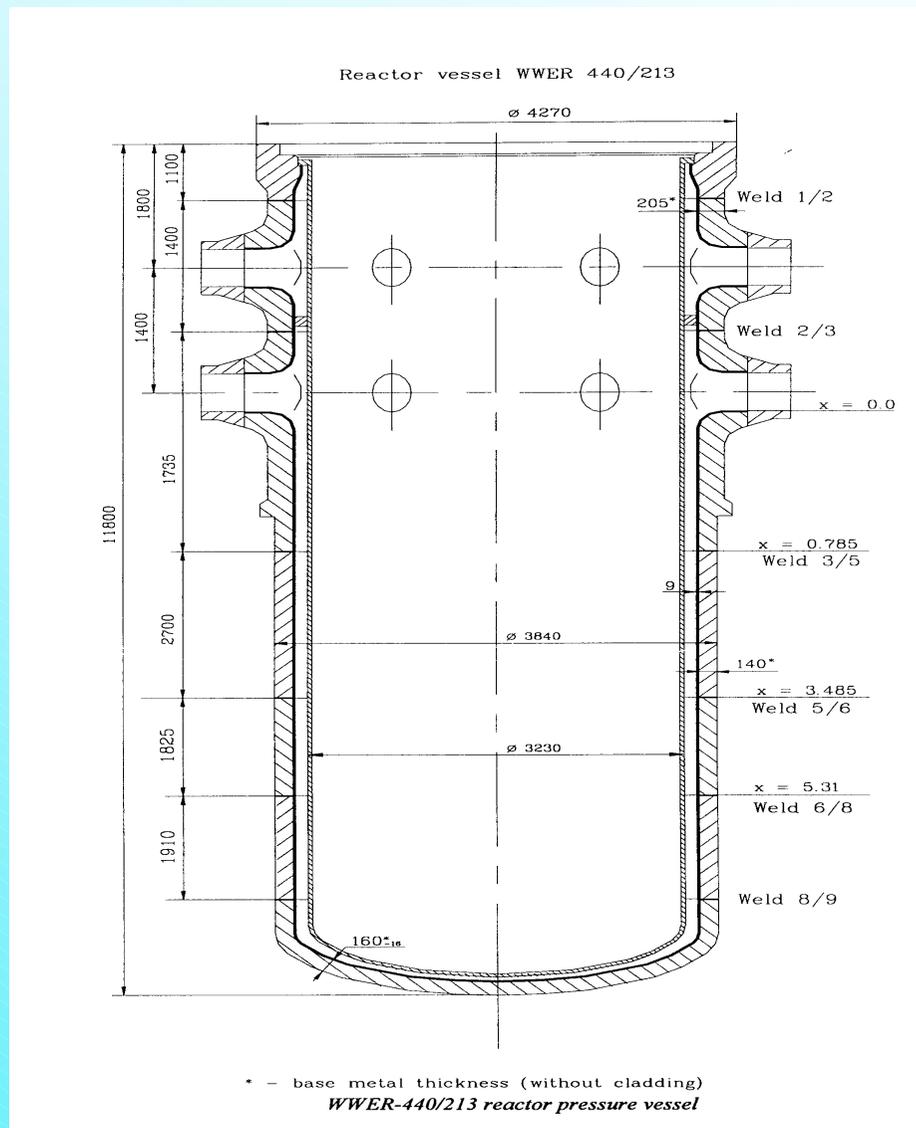


LOCA

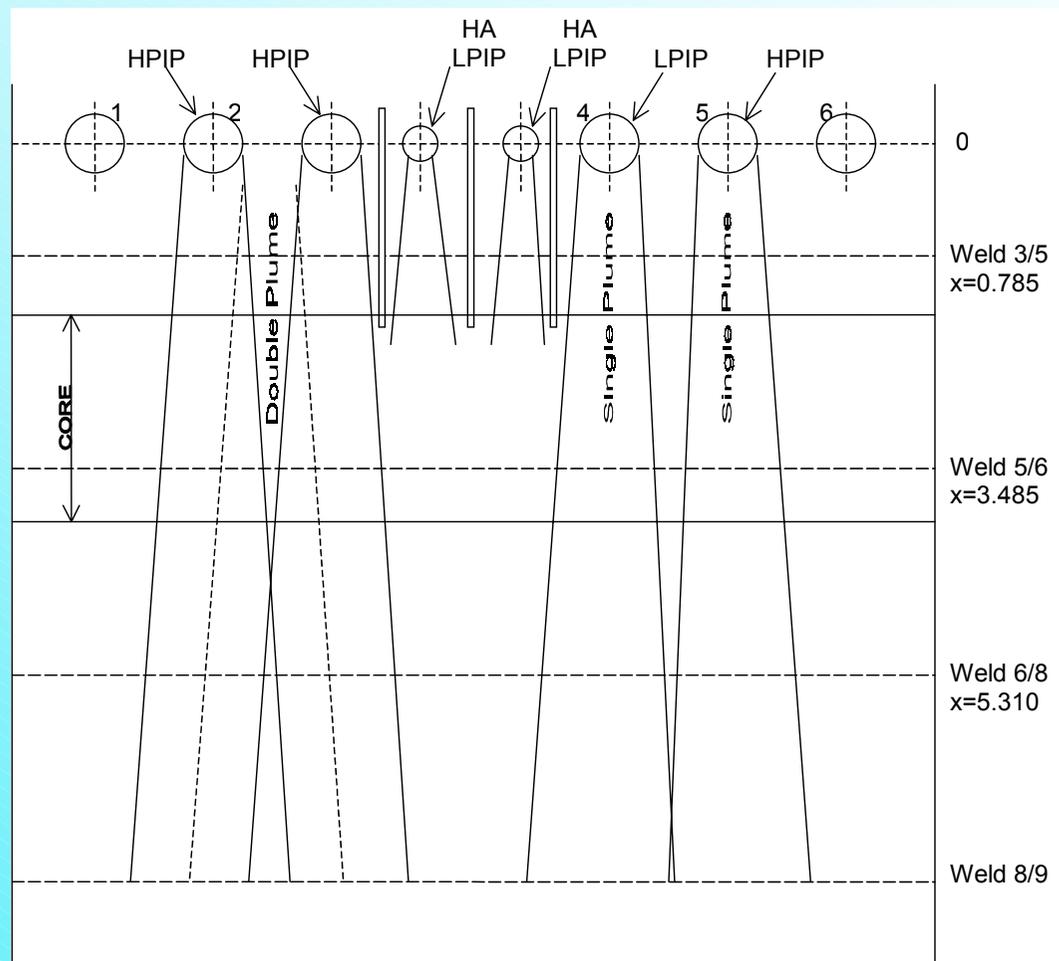
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Relap5/Mod3.2.2.



WWER - 440/213 REACTOR PRESSURE VESSEL



Scheme of plume configuration in downcomer RPV NPP V2



Stuck open PRZ SV

INITIAL EVENT - Inadvertent opening and stuck open one of PRZ SV

(PRZ SV recloses at 60 minutes of transient time)

Plant and calculation initial data

Parameter	Plant value	Calculation value	Remark
Reactor power	10 MW	10 MW	hot zero power
Residual heat	2 MW	2 MW	constant
Primary pressure	12,25 MPa	12,32 MPa	in UP
Coolant temperature at core inlet	260°C	262°C	
Hydroaccumulator pressure	5,4 MPa	5,4 MPa	
Hydroaccumulator water temperature	55°C	35°C	
Water inventory in hydroaccumulator	40 m ³	40 m ³	
Water temperature injected by HPI pumps	55°C	35°C	
Steam generator pressure	4,61 MPa	4,73 MPa	

Boundary conditions

Subjekt	Value	Remark
Operator actions	no	
MCP stop	200 s	high containment pressure signal
Loss of on - and off-site power	no	
PRZ heaters operation	yes	
PRZ spray valves operation	yes	
Feedwater pumps operation	yes	
BRU-K	no	
Reactor protection		
EP-1	9,3 MPa	time delay - 0,5 s
Setpoints and capacities of valves		
<i>PRZ PORV:</i>		
Opening pressure	13,3 MPa	
Closing pressure	12,8 MPa	
Time of opening/closing	1 s	
Steam flow capacity at opening pressure	15 kg/s	
<i>First pressurizer safety valve :</i>		
Opening pressure	14,42 MPa	
Closing pressure	13,05 MPa	
Time of opening/closing	1 s	
Steam flow capacity at opening pressure	32 kg/s	
<i>Second pressurizer safety valve :</i>		
Opening pressure	14,62 MPa	
Closing pressure	13,54 MPa	
Time of opening/closing	1 s	
Steam flow capacity at opening pressure	32 kg/s	
HPI pumps		
Number of pumps in operation	3	
Setpoints on HPI pumps actuating		
Primary pressure drop to, $T_{coolant} \mp 245^{\circ}\text{C}$	9,3 MPa	"large break" signal
PRZ water level decrease, $T_{coolant} \mp 150^{\circ}\text{C}$	2,7 m	
Primary pressure drop to and PRZ water level decrease to, $T_{coolant} \mp 150^{\circ}\text{C}$	10,8 MPa 3,2 m	"small break" signal
Hydroaccumulators		
Number of hydroaccumulators in operation	4	
Emergency feedwater pumps		
Number of pumps in operation	2	
Emergency feedwater pumps actuation setpoints		
SG water level decrease	140 mm	below nominal value

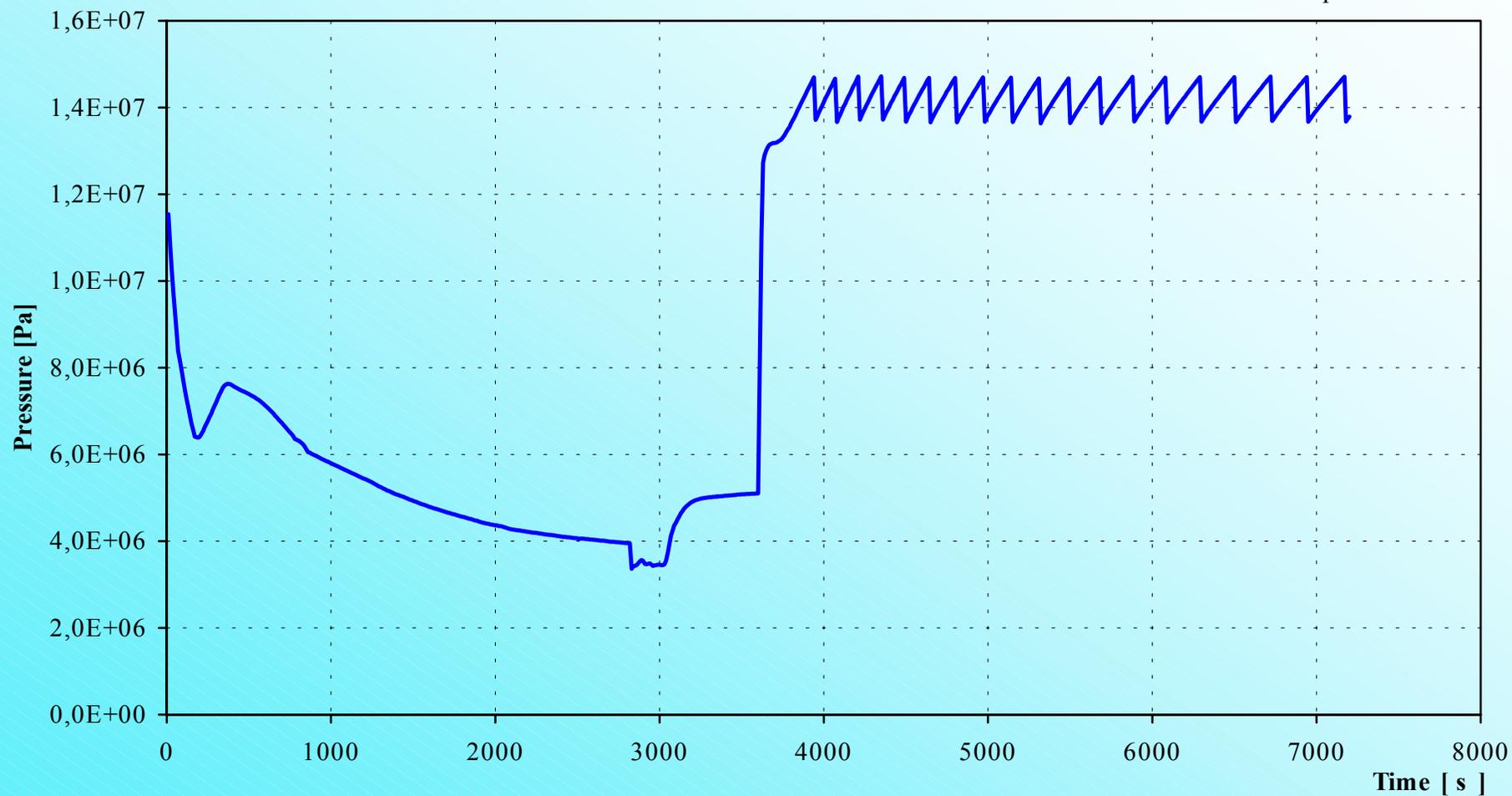
INITIAL EVENT - Inadvertent opening and stuck open one of PRZ SV (PRZ SV recloses at 60 minutes of transient time)

Sequence of events for selected transients

EVENT	Time [s]
Break opening	0
HP injection starts	80
First HA injection starts	185
Increased pressure in containment	200
MCP trip	200
PRZ full	320
Beginning of flow stagnation	440
Second HA injection starts	1120
Beginning of the fast pressuration	3900
First open of pressuriser safety valve	4260
Leak stopped (isolated)	3600
End of calculation	7200

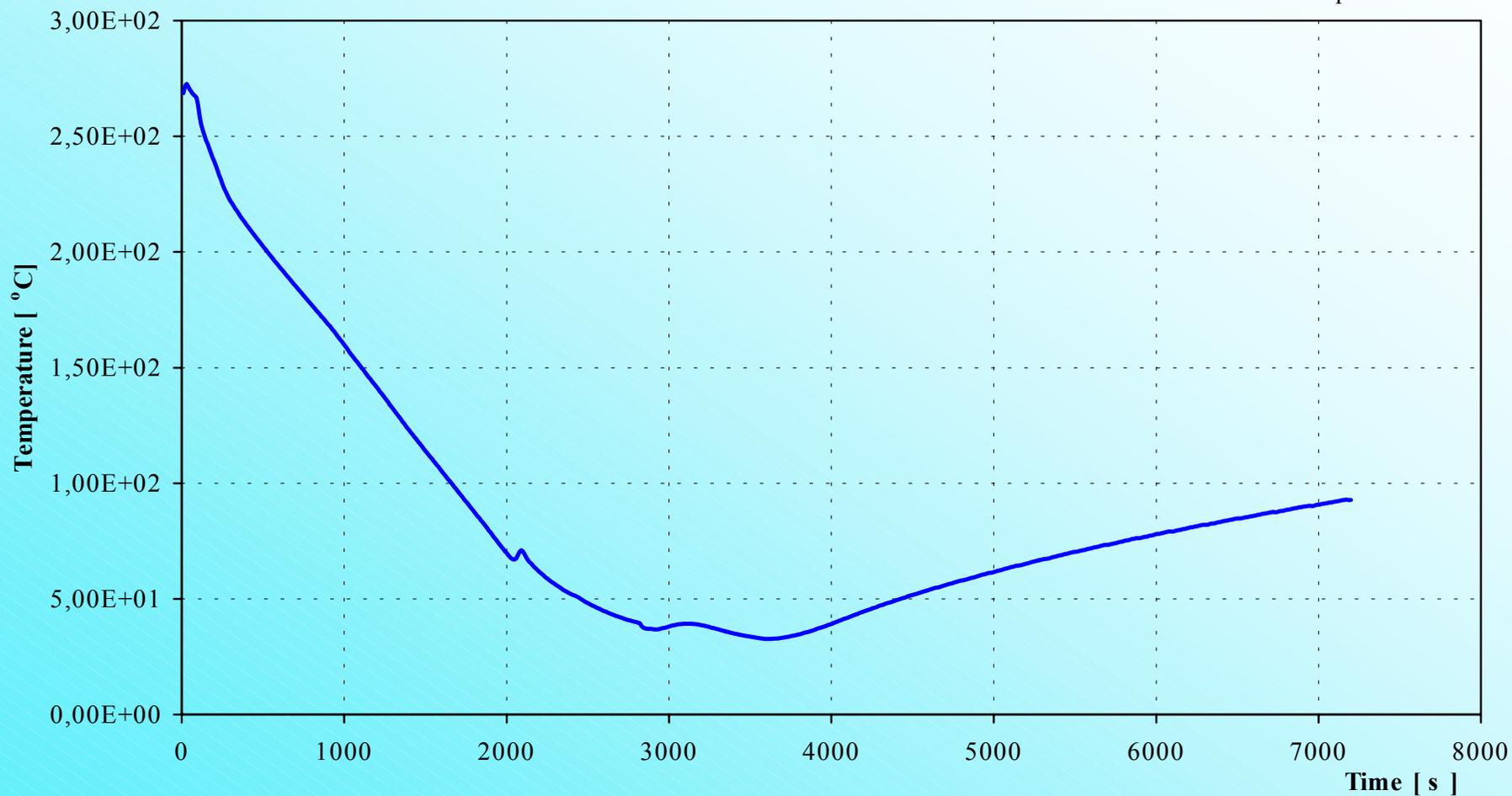
PRZ SV Opening - CORE OUTLET PRESSURE

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Relap5/Mod3.2.2.

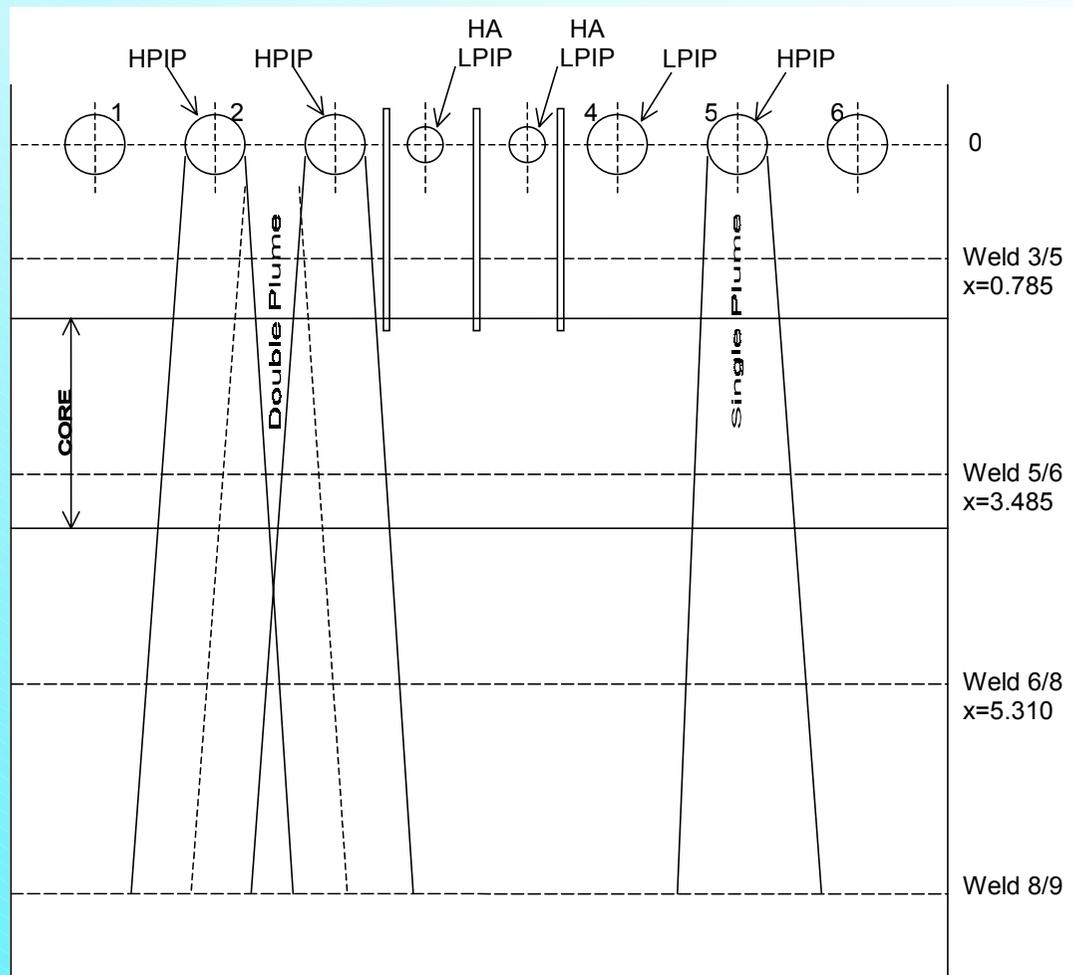


PRZ SV Opening - CORE INLET COOLANT TEMPERATURE

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Relap5/Mod3.2.2.

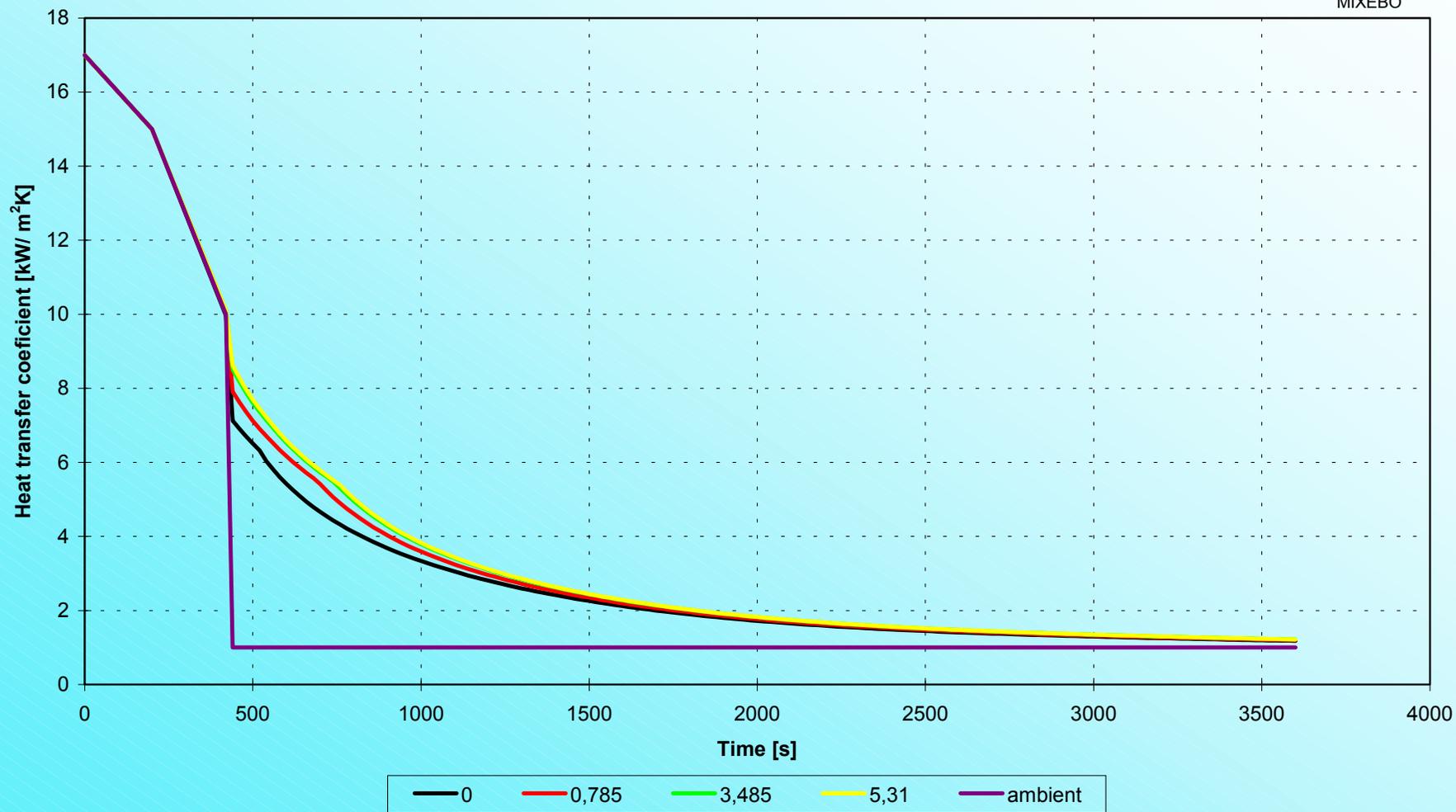


Scheme of plume configuration in downcomer RPV NPP V2



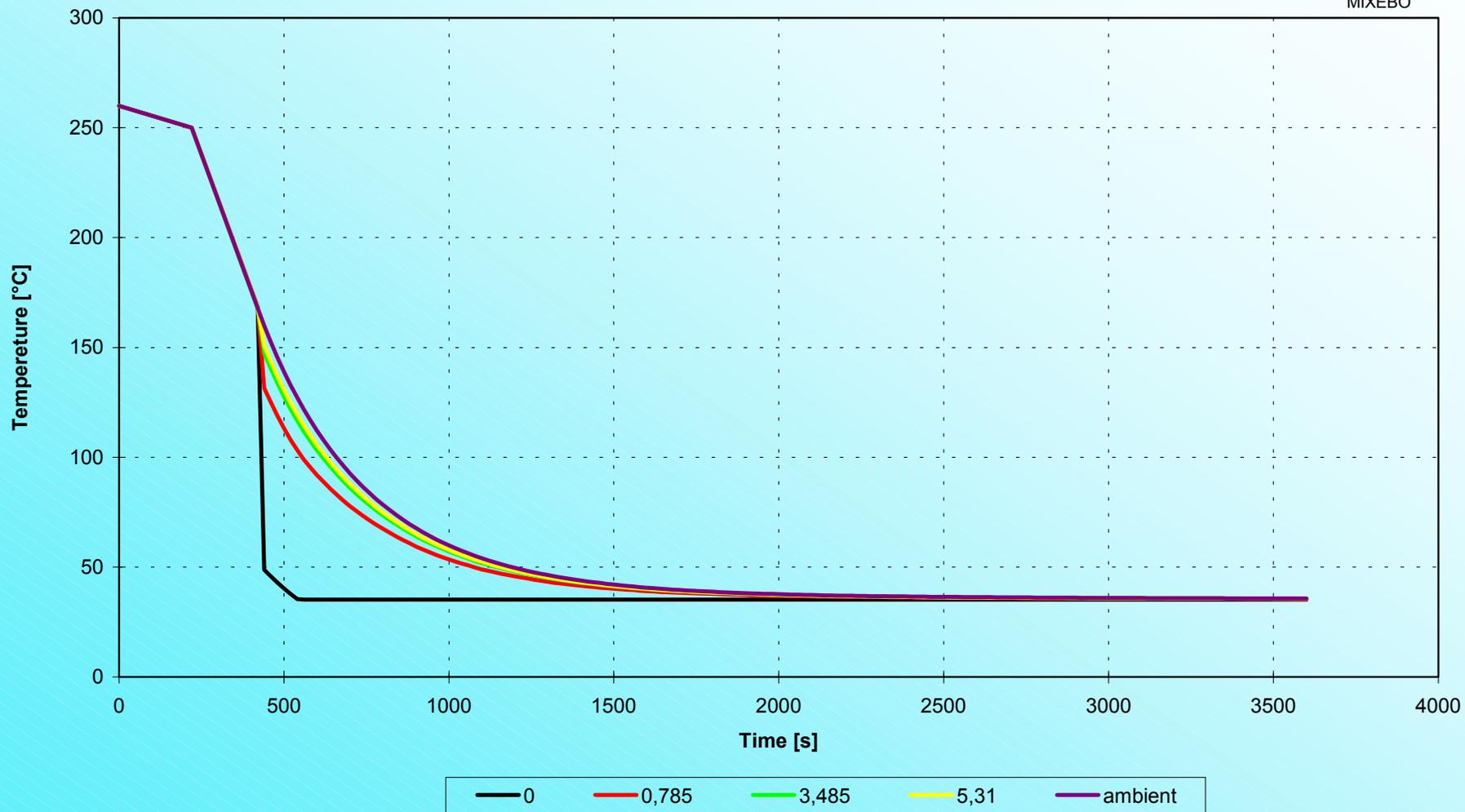
Heat transfer coefficient in cold plume and ambient (double plume)

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MIXEBO



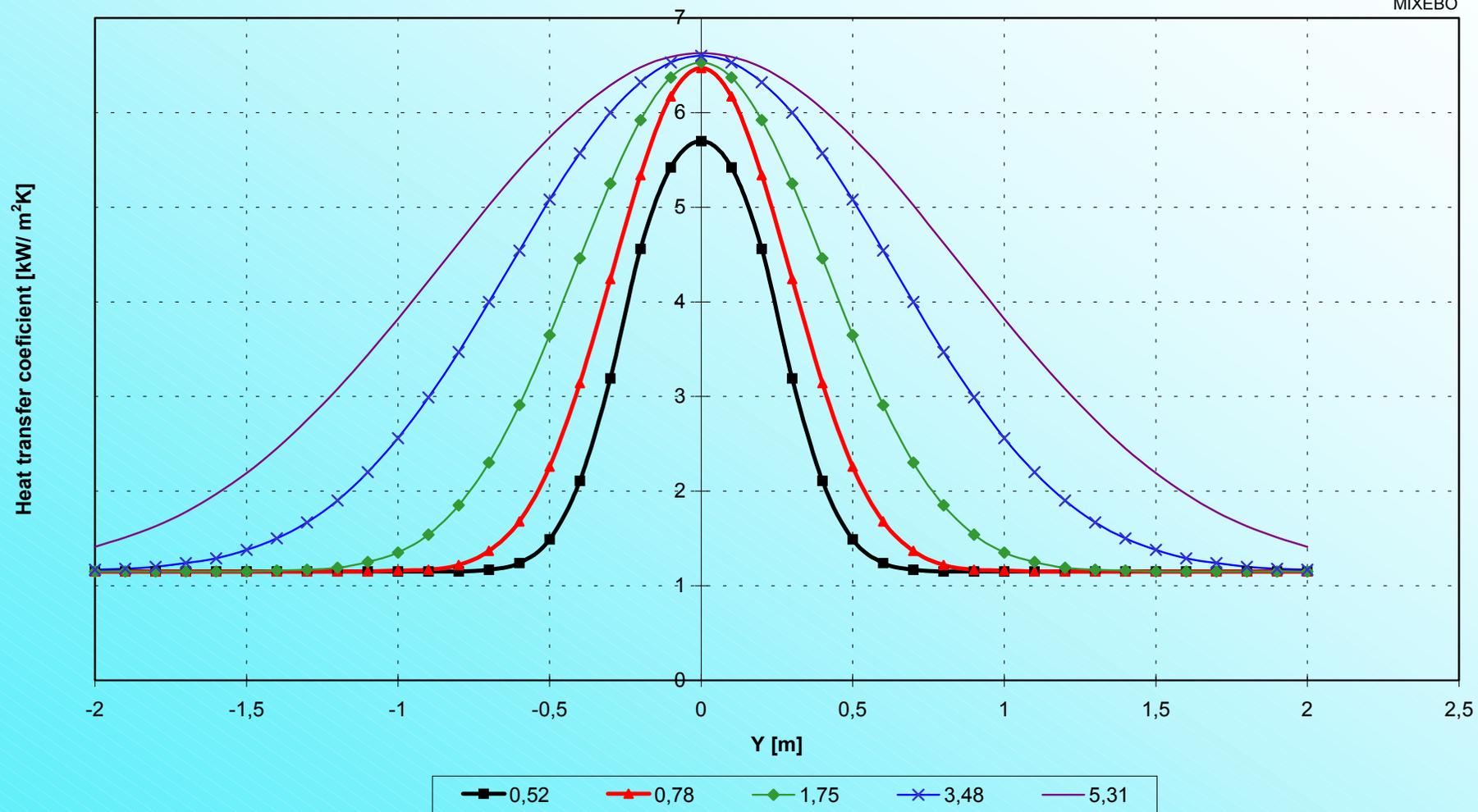
Coolant temperature in cold plume and ambient (double plume)

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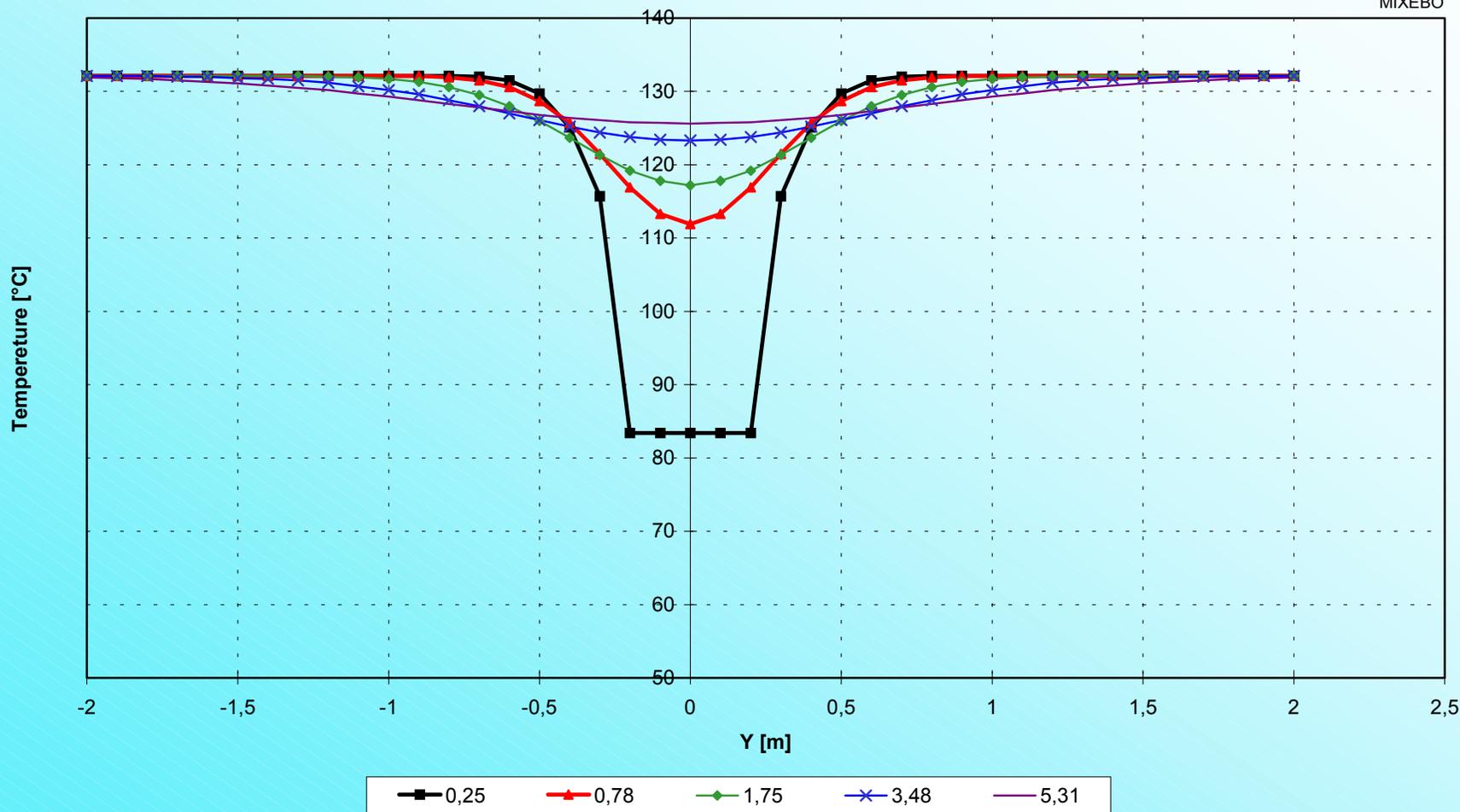
Azimuthal heat transfer coefficient in downcomer at 600s (double plume)

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Azimuthal temperature distribution in downcomer at 600s (double plume)

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THE END

Thank you for your attention